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FINAL REPORT

F49620-92-J-0051 DEF

for the period November 1, 1993 - October 31, 1994

ABSTRACT

The AFOSR support of the Spacewatch program has accomplished a success of historical importance in planetary science and in sky surveillance for the protection of life in the United States and elsewhere. Especially in these last three years a completely new set of techniques and equipment in electronic detection of moving objects has been put to work in a convincing manner of discoveries. The AFOSR Spacewatch System is the talk of the town and recognized by the United States Congress and in foreign countries. It has become the prototype in the forefront of the solution to the life-threatening problem of impacts on Earth due to comets and asteroids, a problem which has come toward the forefront of public attention.

Regarding astrophysical research, an increasing number of moving objects in the solar system is found per year, positions are distributed electronically to others. Our own usage of the discoveries is to study magnitude-frequency relations for a variety of populations in the solar system, such as comets, Centaurs, main-belt asteroids, and objects that can come into the Earth's vicinity. For the near-Earth objects, the discovery rate now is about 25 per year, and expected to increase. These are followed up as much as possible in order to obtain the best possible orbits. The origin of 10-m objects, we call "Arjunas," is being studied, as is the chaotic behavior of large Centaurs in the outer parts of the solar system.

Regarding the new techniques in sky surveillance, there still is lively progress and improvement for the old 0.9-m Spacewatch Telescope, with the development of new scanning techniques, computer programs, and optical devices. The construction of the 1.8-m Spacewatch Telescope is well under way. It is a device of great research interest, even for future generations of planetary scientists. It is of importance as a prototype for future instruments in sky surveillance. It has a compact and stiff design.

DISCOVERY LISTING

The following tables give up-to-date listings of interesting discoveries made with the 0.9-m Spacewatch Telescope. These have been lifted from the large number of discoveries, about 20,000 per year (at least 60,000 positions) that we do not follow up ourselves, but are distributed on electronic mail to investigators elsewhere who often make good use of them by combining them with other observations in order to obtain improved orbits. Scotti has recovered 47 comets, to date.

SPACEWATCH NEAR-EARTH ASTEROIDS

Designation	a	e	i	H (mag)	Diameter(km) (C)	(S)	Discovery Date	Type
1989 UP	1.864	.473	3.86	20.7	0.45	0.23	89 Oct 27	Apollo
1990 SS	1.703	.475	19.39	19.0	0.97	0.50	90 Sep 25	Apollo
1990 TG_1	2.485	.692	9.06	15.0	6.2	3.1	90 Oct 14	Apollo
1990 UN	1.709	.528	3.67	23.5	0.12	0.06	90 Oct 22	Apollo
1990 UO	1.234	.758	29.34	20.5	0.49	0.25	90 Oct 22	Apollo
1990 UP	1.325	.169	28.06	20.5	0.49	0.25	90 Oct 24	Amor
1990 VA	0.985	.279	14.17	19.5	0.77	0.39	90 Nov 9	Aten (5590)
1991 AM	1.695	.695	30.03	16.5	3.1	1.6	91 Jan 14	Apollo
1991 BA	2.243	.682	1.96	28.9	0.010	0.005	91 Jan 18	Apollo
1991 BN	1.443	.398	3.44	20.0	0.62	0.31	91 Jan 19	Apollo
1991 CB_1	1.686	.622	15.83	18.0	1.5	0.8	91 Feb 15	Apollo
1991 EE	2.246	.624	9.77	17.5	1.9	1.0	91 Mar 13	Apollo
1991 FA	1.978	.446	3.08	17.5	1.9	1.0	91 Mar 17	Amor
1991 FE	2.194	.455	3.86	14.9	6.4	3.3	91 Mar 18	Amor (5626)
1991 JR	1.404	.260	10.12	22.5	0.19	0.10	91 May 8	Amor
1991 LH	1.352	.731	52.07	17.5	1.9	1.0	91 June 14	Apollo
1991 RJ_2	2.221	.432	8.96	19.0	0.97	0.50	91 Oct 2	Amor
1991 TT	1.193	.161	14.76	26.0	0.039	0.020	91 Oct 6	Apollo
1991 TU	1.416	.333	7.68	28.5	0.012	0.006	91 Oct 7	Apollo
1991 VA	1.429	.352	6.52	27.0	0.024	0.012	91 Nov 1	Apollo
1991 VG	1.047	.076	0.25	27.6	0.019	0.009	91 Nov 6	Apollo
1991 XA	2.272	.569	5.26	23.5	0.12	0.06	91 Dec 3	Apollo
1992 AE	2.203	.437	6.39	15.0	6.2	3.1	92 Jan 10	Amor
1992 BA	1.341	.068	10.48	20.4	0.51	0.26	92 Jan 27	Amor
1992 DU	1.160	.175	25.06	25.0	0.062	0.031	92 Feb 26	Apollo
1992 HF	1.389	.561	13.29	20.0	0.62	0.31	92 Apr 24	Apollo
1992 JD	1.034	.032	13.59	25.0	0.062	0.031	92 May 3	Apollo
1992 SY	2.217	.554	8.16	18.0	1.5	0.78	92 Sep 27	Amor
1992 SZ	2.177	.460	9.27	19.5	0.77	0.39	92 Sep 28	Amor

Designation	a	e	i	H (mag)	Diameter(km) (C)	(S)	Discovery Date	Type
1992 TB	1.341	.459	28.10	17.0	2.4	1.2	92 Oct 2	Apollo
1989 ML	1.279	.146	4.64	19.5	0.77	0.39	92 Nov 19	Amor
1992 YD_3	1.169	.139	27.75	26.0	0.039	0.020	92 Dec 27	Amor
1993 BD_2	2.136	.396	25.73	18.5	1.2	0.62	93 Jan 22	Amor
1993 BD_3	1.618	.369	0.87	26.0	0.039	0.020	93 Jan 26	Amor
1991 CB_1	1.687	.595	14.57	18.0	1.5	0.8	93 Jan 26	Apollo (1993 BV_3)
1993 BU_3	2.387	.510	5.25	21.0	0.39	0.20	93 Jan 29	Amor
1993 DA	0.936	.093	12.33	26.6	0.029	0.015	93 Feb 17	Aten
1993 DQ_1	2.030	.494	10.12	16.7	2.8	1.4	93 Feb 26	Amor
1993 EA	1.272	.586	5.06	16.8	2.7	1.4	93 Mar 3	Apollo
1993 FS	2.226	.425	10.14	20.0	0.62	0.31	93 Mar 25	Amor
1993 FA_1	1.414	.283	20.22	26.0	0.039	0.020	93 Mar 28	Amor
1993 GD	1.102	.238	15.46	20.5	0.49	0.25	93 Apr 15	Apollo
1993 HA	1.279	.144	7.74	19.8	0.67	0.34	93 Apr 17	Amor
1993 HC	1.990	.508	9.40	20.7	0.45	0.23	93 Apr 20	Apollo
1993 HD	1.445	.664	5.74	25.0	0.062	0.031	93 Apr 20	Apollo
1993 HP_1	1.921	.493	7.78	27.0	0.024	0.012	93 Apr 27	Apollo
1993 KA	1.255	.198	6.05	26.0	0.039	0.020	93 May 17	Amor
1993 KA_2	2.227	.775	3.19	29.2	0.004	0.009	93 May 21	Apollo
1993 PB	1.426	.608	41.03	16.4	3.2	1.6	93 Aug 13	Apollo
1993 PC	1.155	.476	4.18	18.7	1.1	0.57	93 Aug 15	Apollo
1993 QA	1.473	.310	12.26	17.9	1.6	0.82	93 Aug 16	Apollo
1993 RA	1.998	.444	6.22	20.3	0.54	0.27	93 Sep 9	Amor
1993 TQ_2	2.007	.425	6.11	20.0	0.62	0.31	93 Oct 11	Amor
1993 TZ	2.179	.597	4.36	26.0	0.048	0.020	93 Oct 15	Apollo
1993 UD	1.345	.203	24.28	20.5	0.49	0.25	93 Oct 16	Amor
1993 UA	2.094	.542	4.69	26.0	0.048	0.020	93 Oct 21	Apollo
1993 VC	2.973	.562	3.33	17.5	1.9	1.0	93 Nov 8	Amor
1993 VD	0.878	.590	2.22	21.0	0.39	0.19	93 Nov 9	Aten
1991 WA	1.575	.642	39.65	17.5	1.9	1.0	93 Dec 14	Apollo
1994 BB	2.382	.501	1.31	23.0	0.15	0.08	94 Jan 18	Amor
1994 CB	1.148	.145	18.16	21.0	0.39	0.20	94 Feb 3	Apollo
1994 CC	1.636	.416	4.63	17.0	2.4	1.2	94 Feb 3	Apollo
1994 CJ_1	1.433	.291	2.09	21.0	0.39	0.20	94 Feb 10	Apollo
1994 CK_1	1.879	.531	3.42	18.0	1.5	0.78	94 Feb 10	Apollo
1994 CN_2	1.568	.427	1.50	16.0	3.9	2.0	94 Feb 15	Apollo
1994 EK	1.494	.421	4.34	21.1	0.37	0.19	94 Mar 7	Apollo
1994 EU	1.380	.280	6.50	25.9	0.041	0.021	94 Mar 10	Apollo
1994 ES_1	1.387	.587	1.14	28.2	0.014	0.007	94 Mar 14	Apollo
1994 FA	1.736	.416	13.05	25.0	0.062	0.031	94 Mar 16	Amor
1994 GK	1.994	.613	5.73	24.0	0.10	0.05	94 Apr 7	Apollo
1994 GL	0.683	.505	3.65	24.0	0.10	0.05	94 Apr 7	Aten
1994 GV	2.012	.519	0.47	27.5	0.019	0.010	94 Apr 13	Apollo
1994 RB	2.474	.637	26.57	23.0	0.15	0.08	94 Sep 1	Apollo
1994 TA_2	2.586	.510	6.98	20.0	0.62	0.31	94 Oct 9	Amor
1994 TE_2	2.305	.455	5.47	22.0	0.24	0.12	94 Oct 11	Amor
1994 UG	1.262	.403	7.15	20.3	0.54	0.27	94 Oct 28	Apollo
1994 US	2.958	.600	8.85	21.2	0.35	0.18	94 Oct 29	Amor

Designation	a	e	i	H (mag)	Diameter(km) (C)	(S)	Discovery Date	Type
	1.638	.445	3.38	27.7	0.018	0.009	94 Nov 1	Apollo
1994 VV_1	1.963	.433	11.44	17.4	2.0	1.0	94 Nov 10	Amor
1994 XD	2.275	.716	4.21	19.2	0.89	0.45	94 Dec 1	Apollo
1994 XG	1.692	.595	13.95	18.3	1.3	0.68	94 Dec 2	Apollo
1994 XM_1	2.010	.554	5.62	28.4	0.013	0.0065	94 Dec 9	Apollo

SPACEWATCH OUTSTANDING ASTEROID DISCOVERIES

Designation	a	e	i	H (mag)	Diameter(km) (C)	(S)	Discovery Date	Type
(5145)Pholus	20.480	.576	24.69	7.3	213	108	92 Jan 9	Centaur (5145)
1992 JG	2.265	.424	5.58	17.0	2.4	1.2	92 May 2	Deep Mars Crosser
1992 XA	3.525	.483	25.03	18.0	1.5	0.78	92 Dec 1	Griqua?
1993 HA_2	24.818	.550	16.70	9.5	75	40	93 Apr 26	Centaur
1993 TR_2	2.609	.487	15.10	20.3	0.54	0.27	93 Oct 12	Deep Mars Crosser
1994 VA_1	1.573	.174	7.60	18.9	1.02	0.52	94 Nov 5	MC Mars Crosser
1994 VU_1	2.275	.413	5.54	17.9	1.6	0.82	94 Nov 9	Deep Mars Crosser

SPACEWATCH COMET DISCOVERIES

Designation		Name	q	e	i	Discovery Date	Time of Perihelion
1991x	1990 XXIX	P/Spacewatch	1.543	0.509	9.97	91 Sep 8	1990 Dec 22.040
1992h		Spacewatch	3.007	0.999936	124.32	92 May 1	1993 Sep 5.550
1993r		P/Spitaler	2.133	0.422	5.77	93 Oct 24	1994 Jan 28.225

RESULTS

Presentations are made at national and international meetings and papers have been written and are being written on several aspects of Spacewatch research as can be seen from the Bibliography at the end of this report. Especially gratifying is that other people are also writing papers and making studies of the Spacewatch results. We have kept no record of this, but estimate that at present there are a few dozen such papers already. There also is a large amount of writing in science journals and even daily papers. We do not have a complete collection, but we have sent a few of those to Dr. Radoski. In addition, at least a dozen television films have

been made at the Spacewatch Telescope for various national and international networks; outstanding is the 26-minute program on German national television made in Hamburg.

Arjunas

The origin of the Arjunas is being investigated in several papers by others as well as by us. These objects could be secondary debris from the Moon, Mars, or from secondary collisions of the near-Earth objects themselves. The magnitude-frequency relation follows the one expected for fragmentation. However, we found that toward smaller sizes there is an excess in the number of objects.

Centaurs

Centaur asteroids orbit in the outer solar system and may be a link between the Oort cloud and the Jupiter family of short-period comets. Of the three observed by Spacewatch thus far, (2060) Chiron has recently exhibited cometary activity. (5145) Pholus (discovered by Spacewatch in January, 1992) and 1993 HA2 (discovered by Spacewatch in April, 1993) have shown no signs of cometary activity, but instead appear to the reddest objects known in the solar system. This may indicate a cosmic ray-induced organic crust present on new comets.

PREPARATIONS FOR NEW RESEARCH

In the last year of this reporting period we have begun a new era of studying new populations, as well as continuing research on the Arjunas, with a paper in *Icarus* by Rabinowitz, and the Centaurs, with a paper in preparation by Jedicke.

Objects in the Outer Parts of the Solar System

Scotti is working on a Ph.D. dissertation on objects in the outer parts of the solar system. There is a nagging problem about the lack of discovery by Spacewatch of new comets. We had predicted to find about six per year, and we find at best one per year. There may be a fundamental physical reason for this, but we have not fully expressed this problem nor its solution. It may have to do with a lower bound to the size of the original planetesimals accreted

from the interstellar dust and gas clouds, possibly on the order of 1 km in diameter. In other words, components of cometary nuclei smaller than 1 km in diameter may not exist.

Asteroid Belt

Jedicke is working on an extensive investigation of populations in the asteroid belt, beginning with the magnitude-frequency relation of the belt as a whole. Additional data are being obtained from the Spacewatch sky surveillance.

Trojans

Jedicke also has made a start with the magnitude-frequency relation of the Trojan asteroids. The Trojans will shed light on some fundamental problems connected with the accretion and origin of the Jupiter system. However, an observational challenge has to be resolved first, namely that the Palomar-Leiden Survey indicates a great difference between the preceding and following Trojan groups, while the work by Shoemaker *et al.* indicates no such difference between the two groups. Better statistics are needed, which we will obtain from Spacewatch observations.

New Surveillance Techniques

In our technical work also, a new era is upon us. Even though the 0.9-m Spacewatch Telescope system is working very well, a major improvement is expected with the addition of a field corrector and we shall know the results of that improvement within the year 1995.

The other great leap is, of course, our bringing the 1.8-m telescope on line for new research. This will happen in the three-year period of research being funded by AFOSR. A status report by Mr. Barr now follows.

Spacewatch Telescope Design and Construction

The current Spacewatch Telescope design concept evolved from earlier plans to build a positionable stationary mountable only to "stare" at selected regions of the sky while carrying its own windscreen for partial protection from the elements. Augmented funding has enabled inclusion of tracking drives, bearings, instrument rotation, and a beam-folding secondary that

shortens the overall structure and, thereby, the cost of a more protective enclosure. Engineering work on the present telescope configuration began in March 1993. A decision to add the beam-folding secondary was made in August 1993 and one to include instrument rotation, tilt, and focus provisions at the instrument mounting location was made in June 1994.

By January 1994, mechanical engineering work on the telescope was well started (design layouts, structural analysis, component specification), detailed drawing work was underway by Mr. Synner using "AutoCad" and fabrication of the lower azimuth structures at the University Instrument Shop (UIS) was in progress. During 1994 and continuing at present, work has progressed well in all three areas.

Generally, it can be stated that the mechanical engineering design is now about 75% completed and the mechanical fabrication is about 50% completed, not including the primary mirror cell or assembly testing. Itemized detail is given in Table 1. Most of the mechanical fabrication has been done at UIS by a group of up to 5 welders and machinists. Exceptions requiring outside assistance have been heat treatment and machining of large weldments (the azimuth base disc and journal weldments) and parts requiring high precision grinding (Azimuth stabilizer units and the altitude drive sector). Purchased commercial components have been ordered as each sub-assembly is released for fabrication. Mr. Synner's office location at UIS enables him to monitor daily progress in the shop while his work is reviewed by Mr. Barr on a weekly basis. Mr. Perry is managing the project and is also responsible for the electrical/electronic aspects of the telescope. Despite the small size of the engineering team and the potential for conflict with other projects at UIS, work has progressed with few problems and the quality of work is satisfactory.

Table 1 summarizes the status of the telescope mechanical sub-assemblies. The major remaining engineering tasks are those related to the optical tube assembly. It is expected that major engineering design will be completed in early 1995. This is about three months later than reported in May 1994 and is due principally to the features added to the instrument package. Shop drawings should be done by mid-1995. Completion of fabrication work at UIS at the present rate of progress is estimated to require about 6-8 months, depending on manpower availability. Assembly of the azimuth mount will commence in 1st quarter 1995, which will allow limited testing of the drive controls. Final assembly of the optical tube assembly onto the

Table 1 - Status of the Telescope Mechanical Systems

December 1994

The items listed here comprise the basic mechanical telescope mounting. Not included are the instruments, electronics, control systems or the optical components. "Engineering design" means a layout ready for detailing into shop drawings. TDB signifies "To be done." Completion of fabrication does not include tests of the unit in the telescope assembly.

	Eng. Design	Shop Dwgs.	Fabrication
Stationary Azimuth Base			
Azimuth Journal Weldment	Done	Done	Done
Azimuth Cable Wrap	Done	Done	Done
Azimuth Central Bearing	Done	Done	Done
Rotating Azimuth Base			
Azimuth Base Disc	Done	Done	Done
Altitude Pedestals	Done	Done	Done
Azimuth Drives (3)	Done	Done	Done
Azimuth Stabilizer Rollers (3)	Done	Done	Done
Azimuth Brakes (2)	Done	Done	Done
Altitude Bearings	TBD	TBD	TBD
Altitude Drive Unit	Done	Done	Started
Optical Tube Assembly			
Primary Mirror Cell	Minor modifications required		
Cell Attachment Brackets	Done	Done	Done
Altitude Drive Sector Assy	Done	Done	Started
Truss Structure & Mirror Cover	TBD	TBD	TBD
Top End Mirror Assy	Started	TBD	TBD
Optical Corrector Housing	TBD	TBD	TBD
Instrument Rotator	Done	Started	TBD
Mid-section Strut Assy	Done	Started	TBD
Assembly & Test	TBD	TBD	TBD

azimuth mount should occur in the 3rd quarter 1995, which will essentially complete the mechanical work required. Procurement of the required optical folding flat and the optical corrector should be started in early 1995 to be available when the telescope assembly is complete.

In conclusion, we thank AFOSR for the crucial support during these past three years. It can safely be said that Spacewatch has continued to exist and operate these past three years only because of AFOSR. We are deeply grateful for this, and for the friendly and efficient manner in which this support has been handled by the AFOSR offices at Bolling Air Force Base.

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Regarding astrophysical research, an increasing number of moving objects in the in the solar system is found per year, positions are distributed electronically to others. Our own usage of the discoveries is to study magnitude-frequency relations for a variety of populations in the solar system, such as comets, Centaurs, main-belt asteroids, and objects that can come into the Earth's vicinity. For the near-Earth objects, the discovery rate now is about 25 percent per year, and expected to increase. These are followed up as much as possible in order to obtain the best possible orbits. The origin of 10-m objects, we call "Arjunas," is being studied, as is the chaotic behavior of large Centaurs in the outer parts of the solar system. Regarding the new techniques in sky surveillance, there still is lively progress and improvement for the old 0.9-m Spacewatch Telescope, with the development of new scanning techniques, computer programs, and optical devices. The construction of the 1.8-m Spacewatch Telescope is well under way. It is a device of great research interest, even for future generations of planetary scientists. It is of importance as a prototype for future instruments in sky surveillance. It has a compact and stiff design.

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